

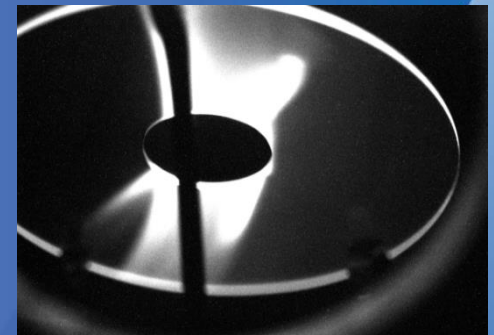
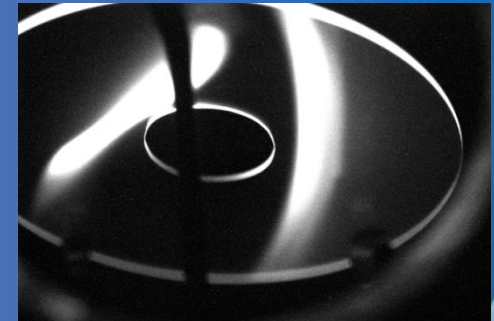
# High Intensity Polarized Electron Source R&D



Cathode preparation Tree



R&D Gatling Gun



First e-beam from 2 gun cathodes July, 2014

Project Leader: John Skaritka

Project Monitor: Ilan Ben-Zvi

C-AD Machine Advisory Committee Meeting Review  
September 2015

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# Talk Outline

- Program Motivation
- Gatling Gun Concept and System Layouts, Photos
- Performance Parameters
- Milestones and Deliverables of the R&D effort
- Near term R&D program for Calendar 2015
- Proposed 2016 -2017 R&D program schedule
- Multiple Individual gun alternatives to the Gatling Gun
- Summary and Acknowledgments

# Motivation

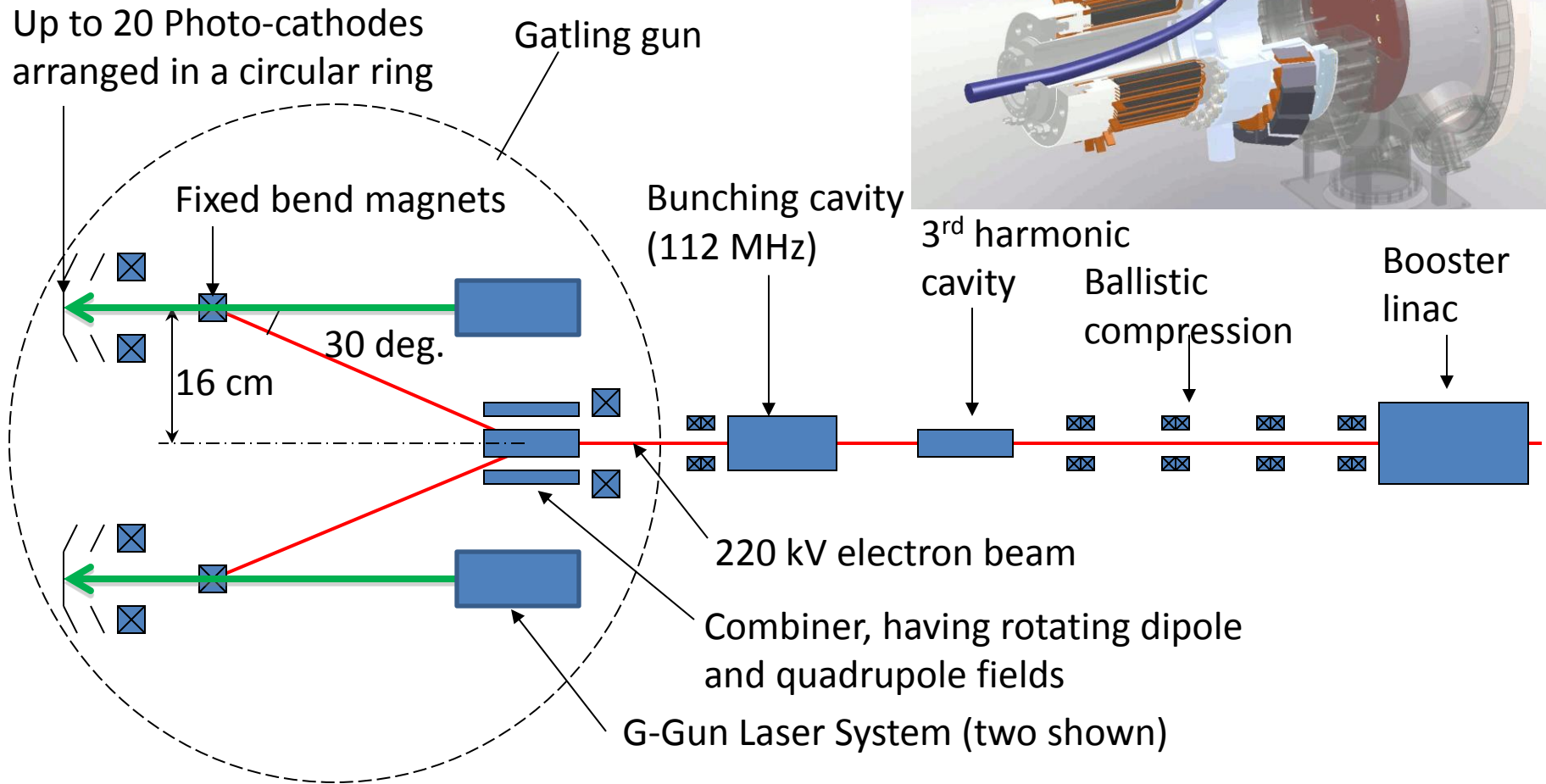
- The “Gatling Gun” approach use beams from multiple cathodes funneled together in a single device to increase the (current \* lifetime) product of the source.
- The goal of the Gatling Gun R&D project is to demonstrate the linearity of a gun system where cathode lifetime is not significantly degraded by the number of cathodes.
- For this R&D program we will use bulk cathodes to specifically:
  - Measure current and lifetime achieved with up to two or more cathodes.
  - No Cathode should degrade the performance of it's neighboring cathodes and thus validate increasing the current\*lifetime product of the Gatling gun multi cathode system.
  - Rigorously study operating scenarios and their affect on gun performance.
  - Characterize and validate performance of the R&D Gun system components so that a final set of vetted parameters can by subscribed to a production gun system for e-RHIC
  - Combining beams from multiple individual Guns will also be studied as an alternative to the Gatling Gun

# Developments affecting Gatling Gun R&D

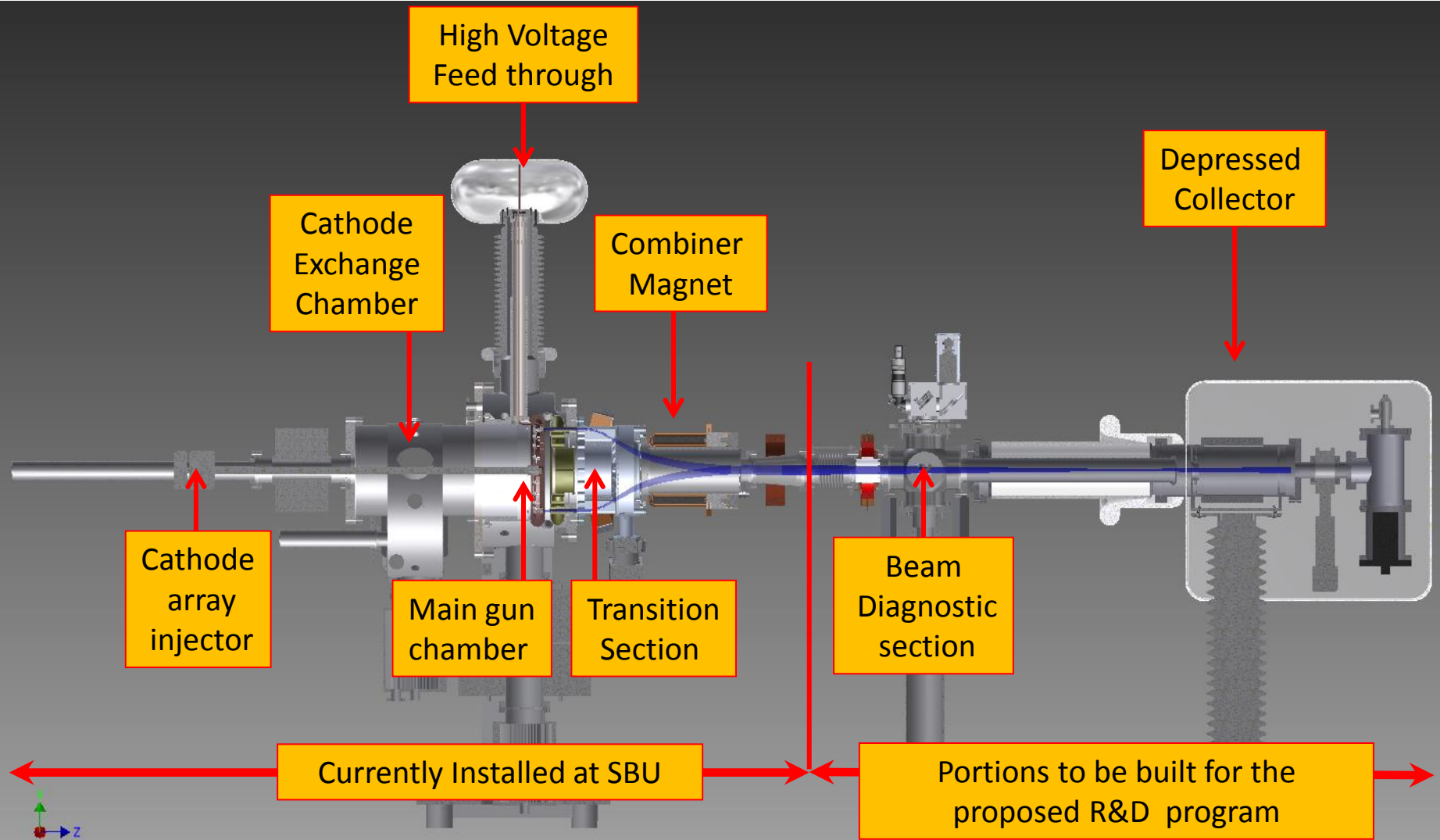
- The Gatling Gun was identified as a important e-RHIC R&D item.
- The Gatling Gun was integrated into the e-RHIC R&D program (as discussed in I. Ben-Zvi) To address and ultimately retire technical and cost risk to the e-RHIC source.
- A R&D program was developed and a detailed recourse loaded schedule was developed and reviewed.
- The Gatling principle will first be demonstrated using bulk GaAs cathodes and super lattice polarized cathode beam to be developed in collaboration with Jlab and MIT.
- A high average current polarized beam, of 4mA was reached by the Jlab. But about 2.5mA is more realistic for individual guns.
- The e-RHIC source developed will include the Gatling Gun along with individual polarized Guns combined to produce a high brightness polarized beam.

# “Gatling Gun” for an e-RHIC injector

For a target photo current of  $> 2.5$  mA/cathode,  
An Ultimate beam current of  $> 50$  mA @ 220 kV  
will require 20 cathodes



# Layout of R&D Gatling Gun System at SBU



# R&D Goals

Demonstrate a polarized electron source that meets e-RHIC requirements:

High average current: Up to 50mA; High Bunch charge: 5.3nC; with Long lifetime

Target photo current of  $> 2.5 \text{ mA/cathode}$  = cathode Life of 800C

Demonstrate Gatling Gun principle in the R&D gun at SBU and demonstrate the combining of beams from multiple single cathode polarized e-guns.

Demonstrate operational cathode life times:

- Max. Average current : 50mA Charge lifetime:  $15,300\text{C}/20 = 765\text{C/cathode}$
- For cathode exchange with min lifetime of 85 hours for 50mA operation
- Min. Average current : 10mA with min. Charge lifetime:  $3060\text{C}/20 = 153\text{C/cathode}$  will provide over one week of continuous e-beam between cathodes exchanges.

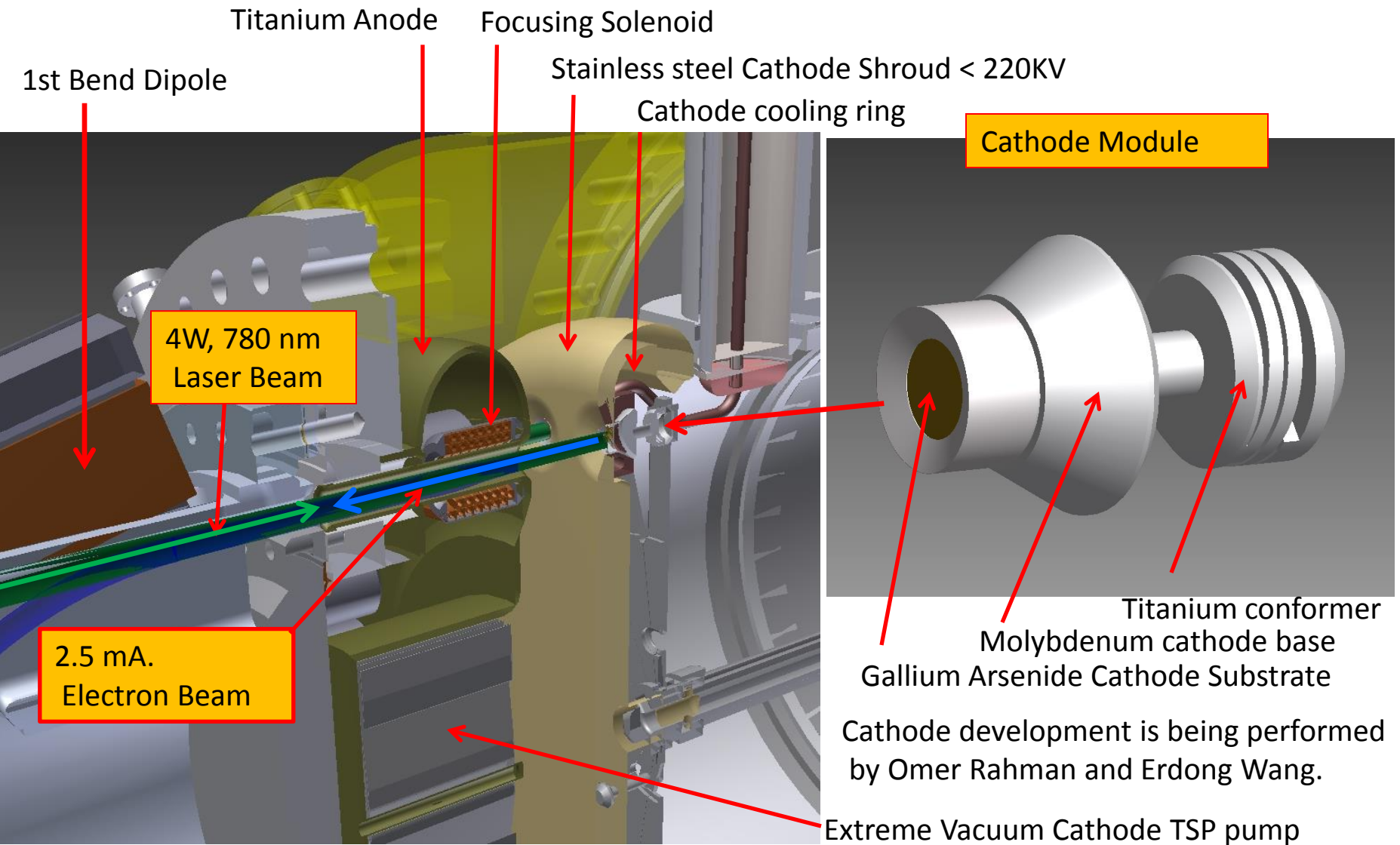
# R&D Program Deliverables

Should adequate R&D resources be provided the following shall be demonstrated.

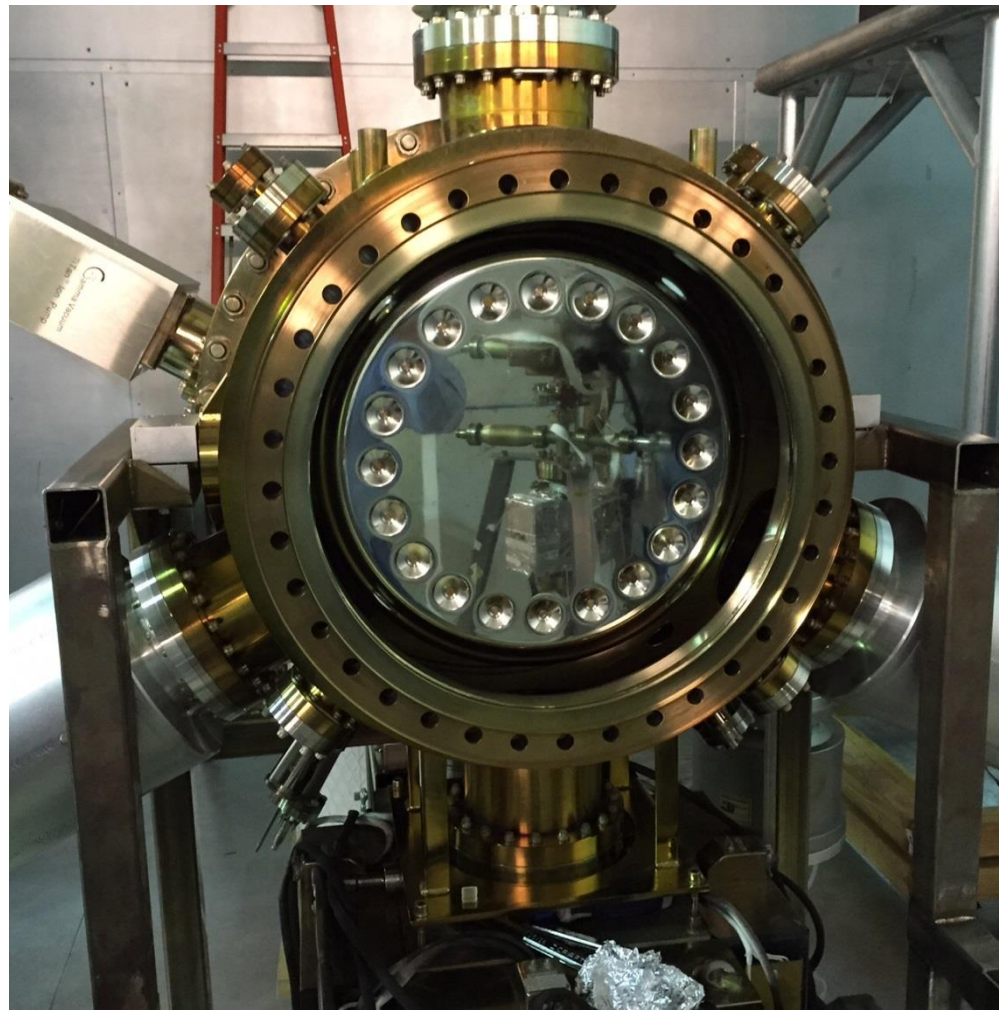
- Linearity of cathode lifetime with respect to the number of cathodes.
- Upgraded of Cathode preparation system for up to 4 cathode capability.
- Gatling Gun e-beam currents in the milliamp. range.
- Combining of polarized e-beams from two or more individual Guns is feasible.



# Section view of Cathode, Anode Gun system

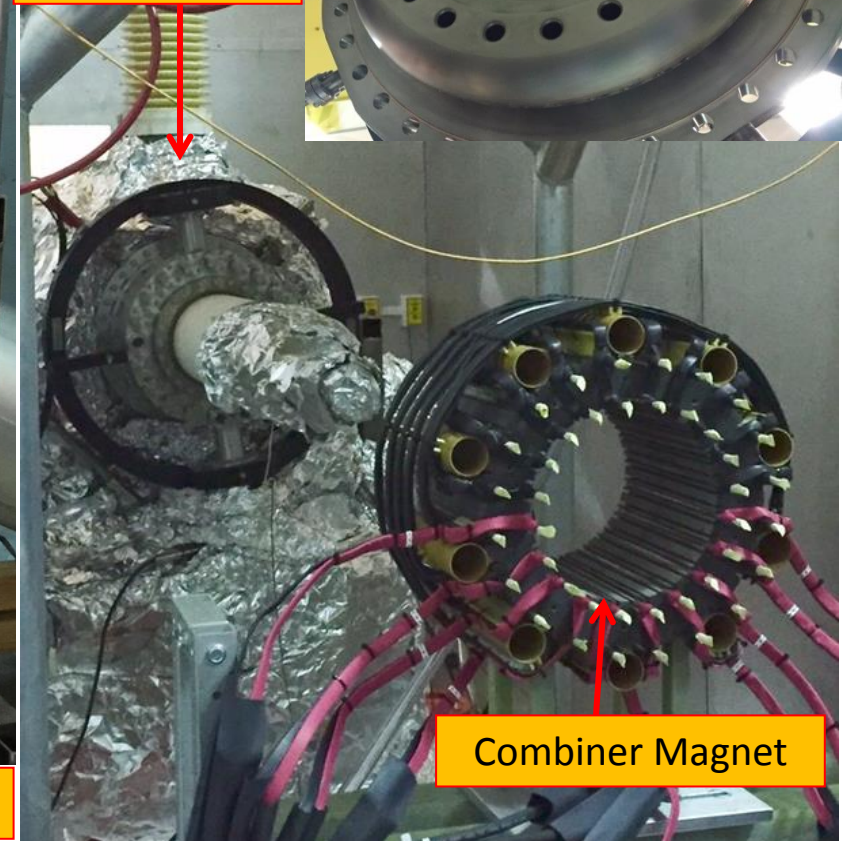
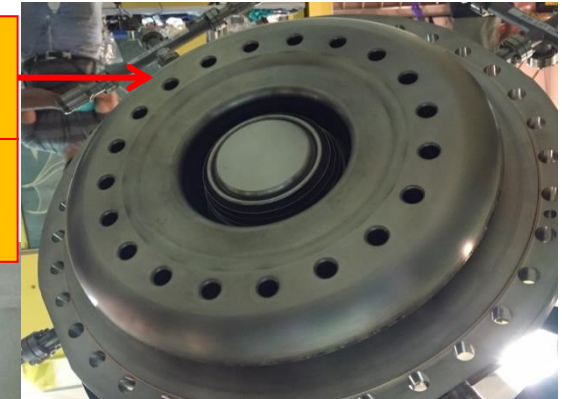


# Views of Gatling Gun System Components at SBU



Main G-Gun chamber open to see 20 cathode shroud

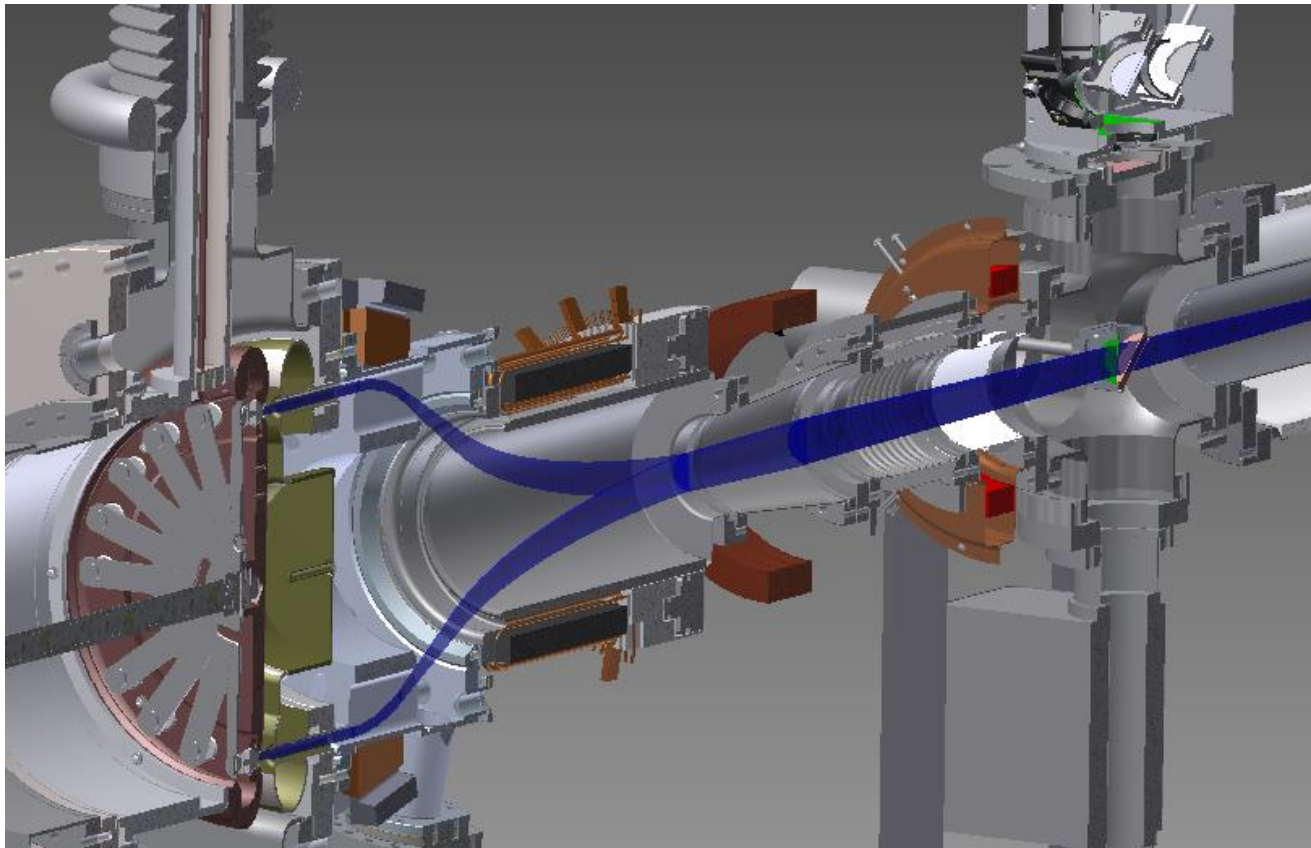
Anode Assembly  
Gun Assy.  
under Bake



Combiner Magnet



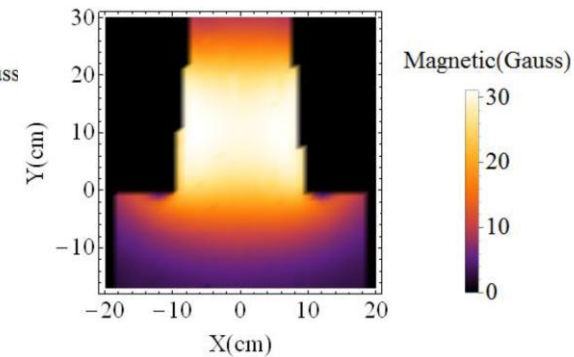
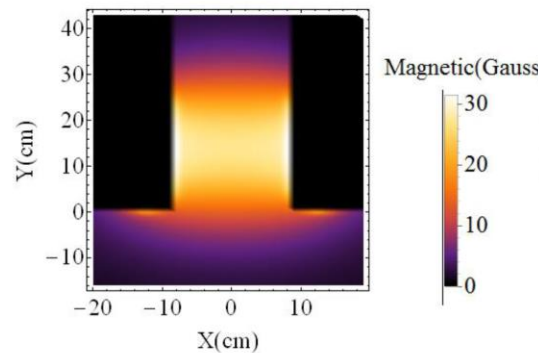
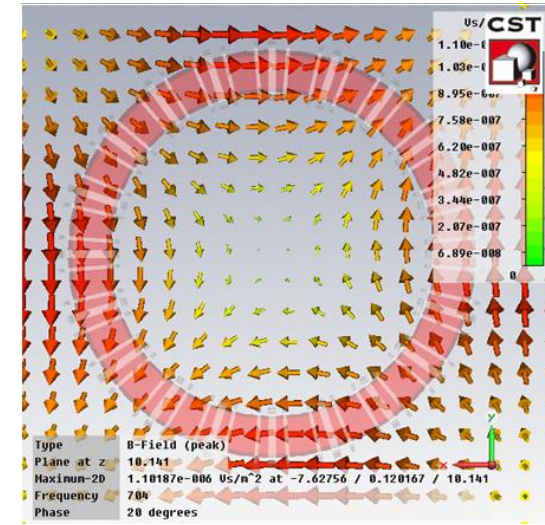
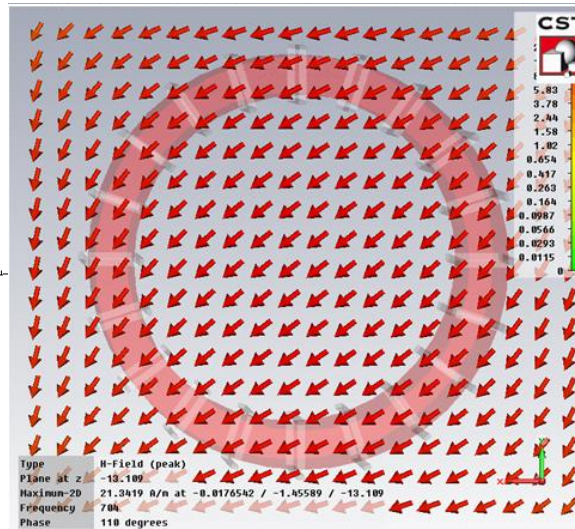
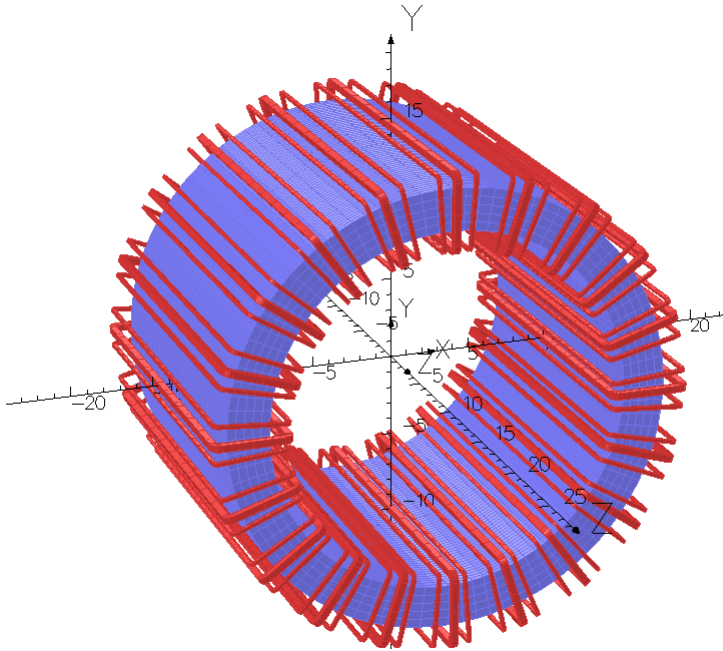
# Two Beam Combiner operation and diagnostics



Section view shows e-beam paths through combiner into the diagnostic cross

Erdong Wang performed Accelerator physics analysis. Bob Lambiase performed Electrical Engineering of High Voltage and Combiner power supply systems and E-beam diagnostics will be provided by David Gassner and the Instrumentation Group.

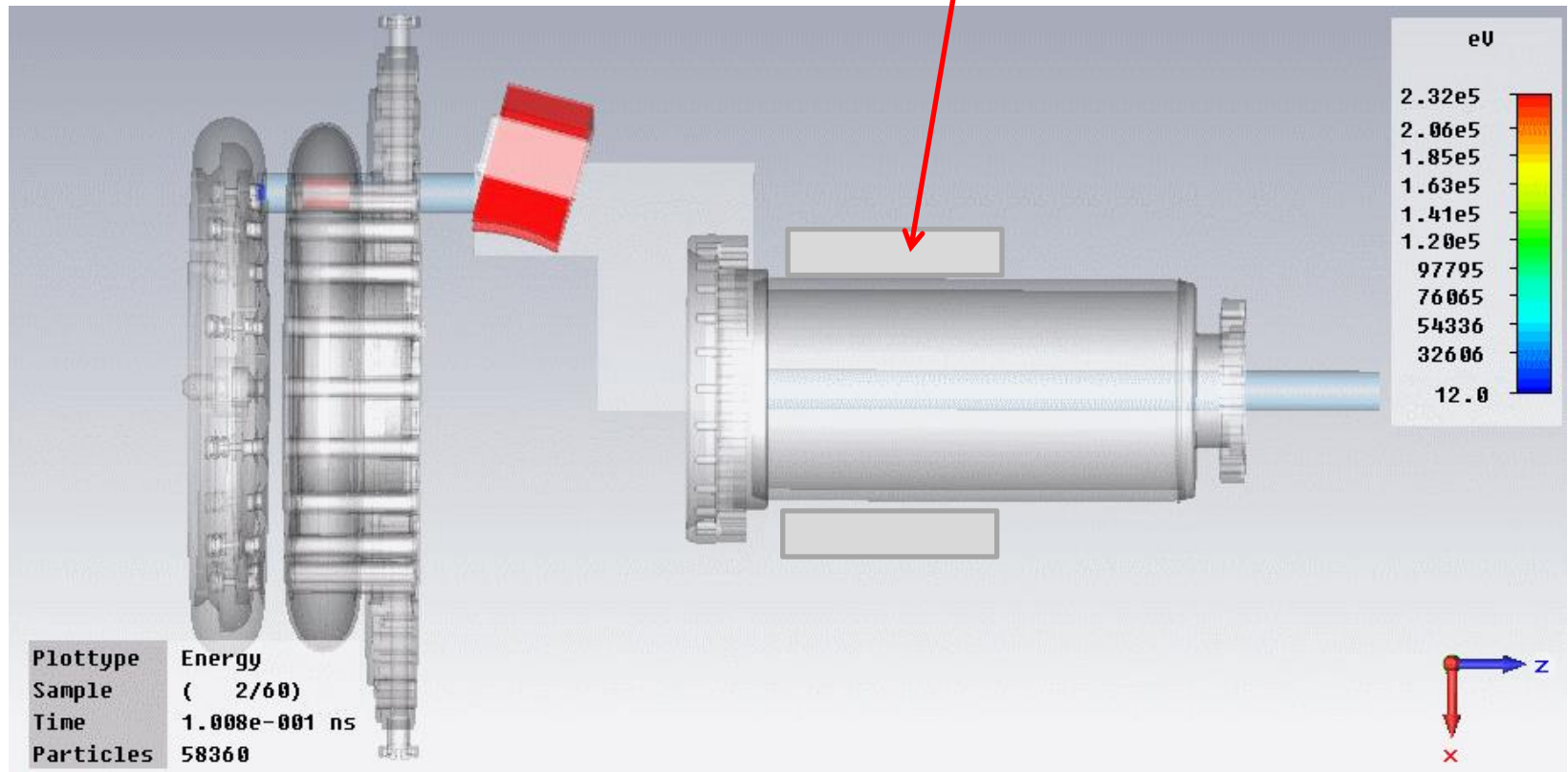
# Beam Combiner Magnet



- Bending the beam by dipole
- Equalize the focusing by quadrupole
- Parameters:  
 $I(t) = I_{od} \cdot \cos(\omega t + \phi)$  where  $I_{od} = 70.7A$   
 $I(t) = I_{oq} \cdot \cos(2(\omega t + \phi))$  where  $I_{oq} = 1.54A$   
 $B(0,0,0) = 25.04G$   
 Freq = 470kHz  
 Bending angle = 29 degrees

# Particle Beam Tracking

Beam Combiner Magnet



Model Developed by  
Erdong Wang

C-AD Machine Advisory Committee Meeting  
September 2015

# R&D Performance Parameters

- Current per cathode > 2.5 m Amps.
  - Bunch length 3.5 ns
  - Charge per bunch 5.3 nC
  - Gun chamber vacuum <  $10^{-11}$  Torr range
  - Cathode voltage > -120 kV
- 
- R&D gun systems performance will be fully studied and characterized to validate the detailed design parameters for an e-RHIC production gun

# Summary of Past Progress of Gatling Gun R&D

- Cathode preparation using bulk GaAs having good quantum efficiency (QE) in the cathode tree at BNL and during industrial testing.
- 
- Ability to transfer Cathodes into the Gun with minor effects to quantum efficiency.
- Vacuum system has reached  $< 10^{-11}$  Torr.
- E-beams (micro amp level) from 2 cathodes have been demonstrated.
- Combiner magnet operation demonstrated funneling two e-beams onto a common axis into a Faraday cup.
- 
- Measured radiation levels compare favorably with models.
- After Industrial testing completed, Gun system disassembled and shipped to SBU.



## Progress of Gatling Gun R&D during FY15

- Over the past year the Gatling Gun System has been transferred from industry and established at SBU:
  - SBU Laboratory space cleared and prepared for Gun Lab.
  - Improvements made to HV and vacuum systems components
  - High voltage enclosure erected.
  - New power and safety systems added to Lab Space.
  - Gatling Gun and Tree systems Reassembled.
  - Reestablish combiner and laser performance
  - High voltage conditioning studies started,
  - Bulk cathode preparation tree demonstrated at SBU and improvements to it's system implemented, additional testing underway.



# Near Term Milestones

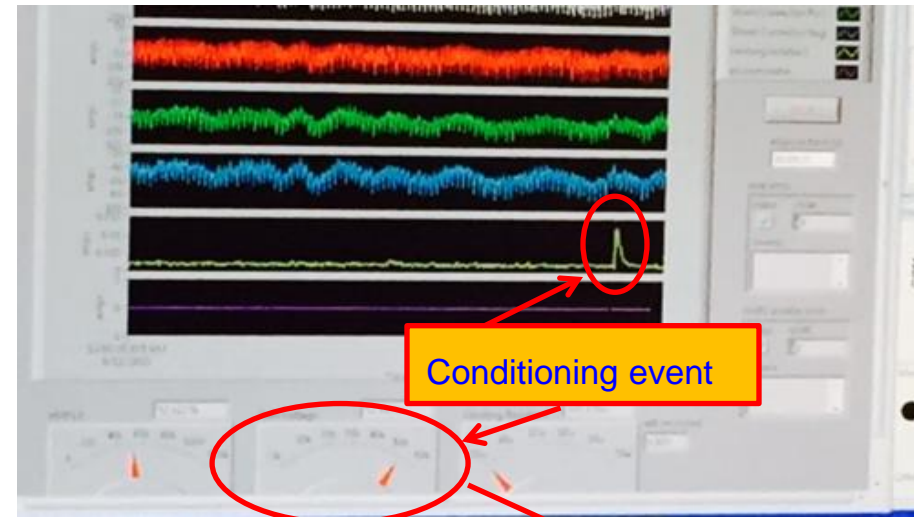
- Milestone #1: 8/15- Reestablish Gatling Gun system performance since Industrial testing last year at SBU. Gatling Gun vessel Vacuum level  $10^{-11}$  Torr, Conditioning voltage  $> 60$  kV
- Milestone #2: 9/15-Demonstrate cathode production with QE  $> 5\%$  in cathode preparation system at SBU.
- Milestone #3: 10/15-Demonstrate electron beams from GaAs bulk cathodes with beam currents  $< 100$  micro Amps.
- Milestone #4: 12/15-Demonstrate BNL super-lattice cathode in preparation system, quantum efficiency of  $0.1\%$  .
- Milestone #5: 12/15- Program Review – Gatling Gun Advisory Committee

# Gun Conditioning Underway

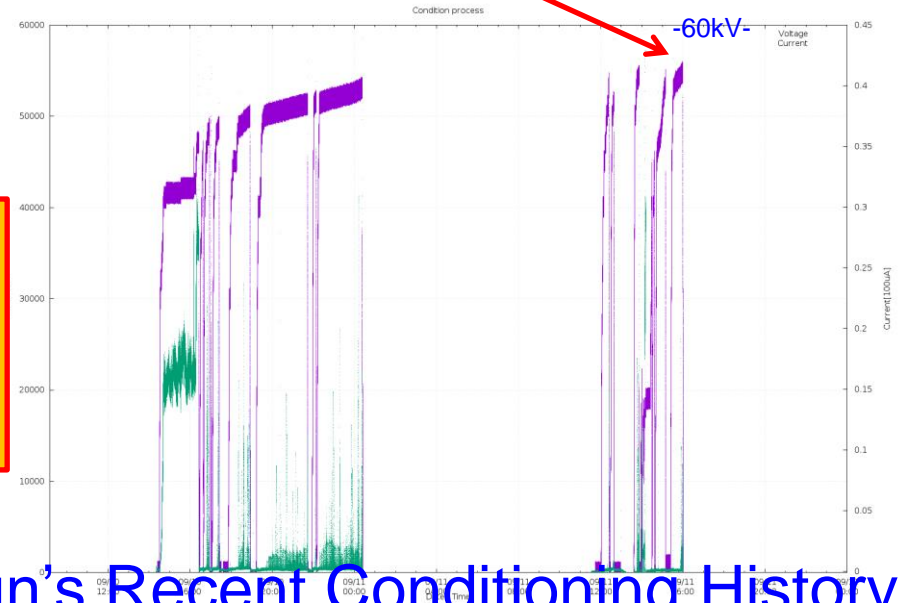
- After initial conditioning earlier this year, Improvements to the Cathode preparation tree took priority in August but conditioning started up again in September.



- Photo taken one early morning at SBU where Gatling Gun voltage has reached 55.4 kV.



Cathode Voltage



## Gun's Recent Conditioning History

# Major Project Milestones FY16-18

- Milestone#6: 2/16: e-beam currents from two cathodes up to 100 micro Amps.
- Milestone#7: 8/16: e-beam from one or more cathodes of up to 1m Amp. range
- Milestone#8: 12/16: e-beam currents by more than one cathode of up to 2.5 m Amps.
- Milestone#9: 3/17: Demonstrate e-beam currents for at least two cathodes with beam currents of up to 2.5 m Amps. per cathode and achieve bunch parameters of 5.3 nC per bunch and bunch length of 3.5 ns
- Milestone#10: 6/17: R&D Gun studies completed, by fully validating the design.
- Milestone# 11: 9/17: Production Gun Preliminary Design Review

# Individual Guns Alternative to the Gatling Gun

- e-guns using Super lattice Cathodes have been developed at Jefferson Lab.
- Collaboration with Jefferson Lab shall transfer Super lattice preparation and use methods to BNL can be used in the following combining concept.

Preparation Chamber

Activation Laser

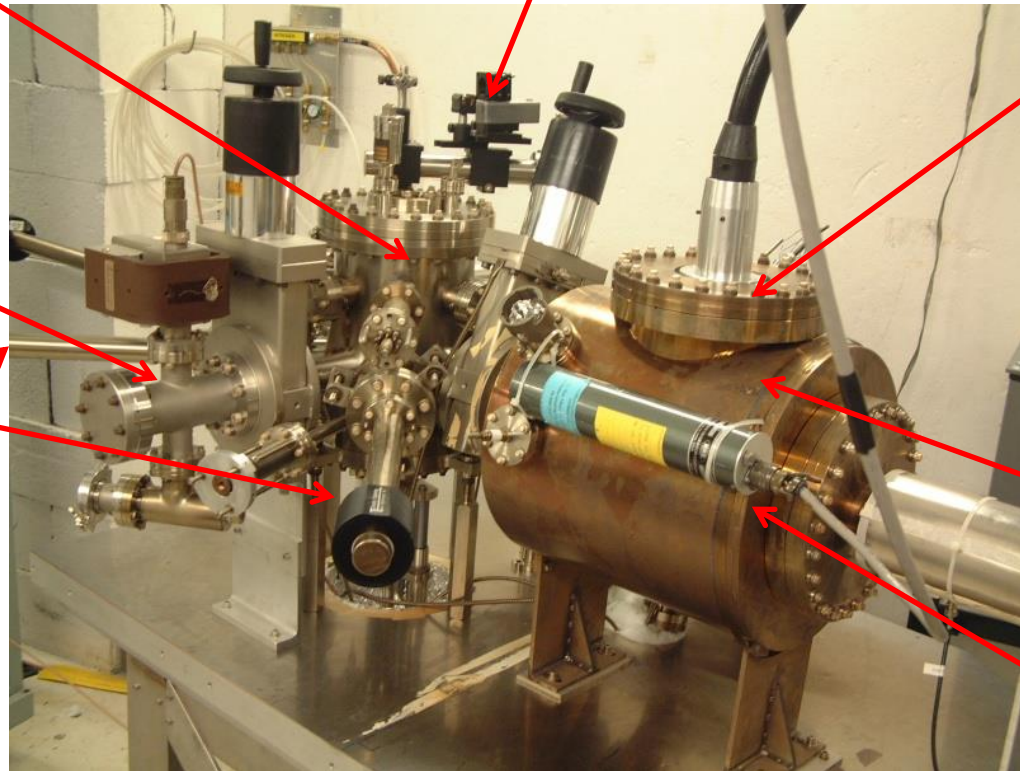


HV Chamber

x-ray Detector

Loading Chamber

Storage Manipulators



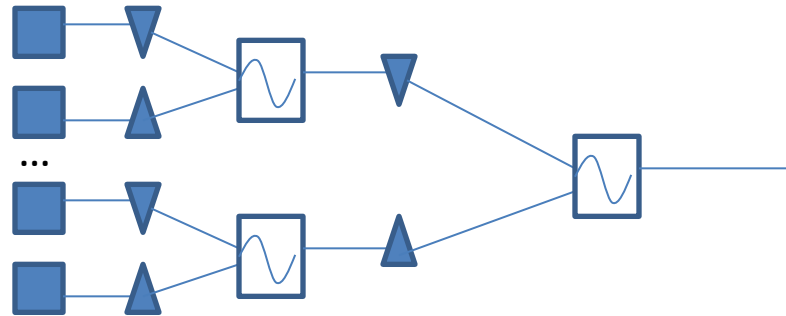
Puck (Mo)

Ring (Ta)

GaAs

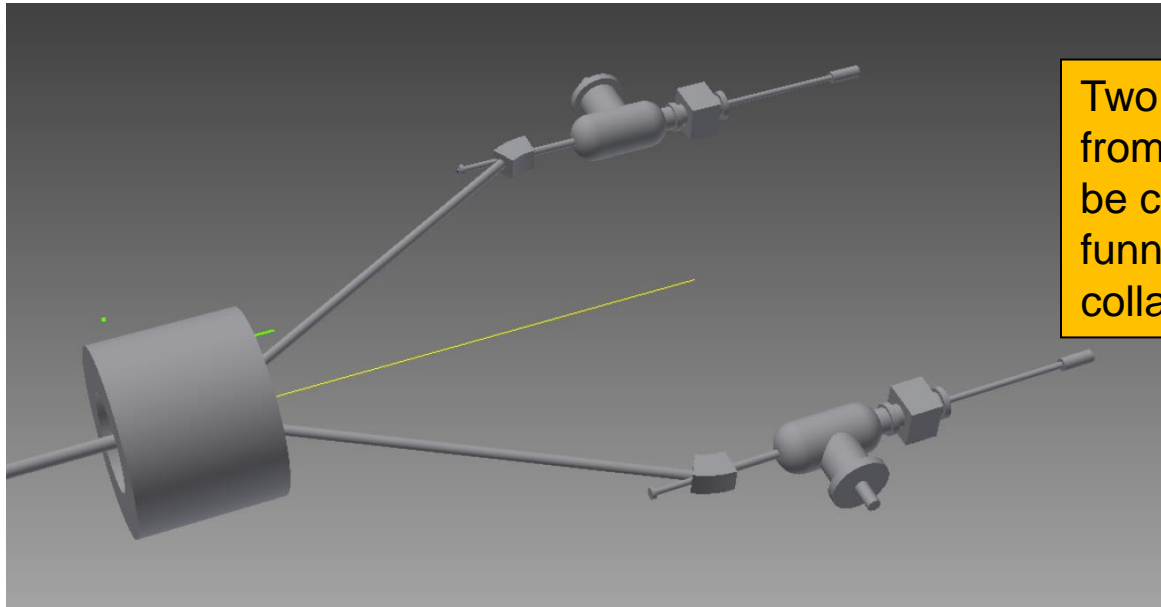


# Multi-Polarized Gun Combination Concepts



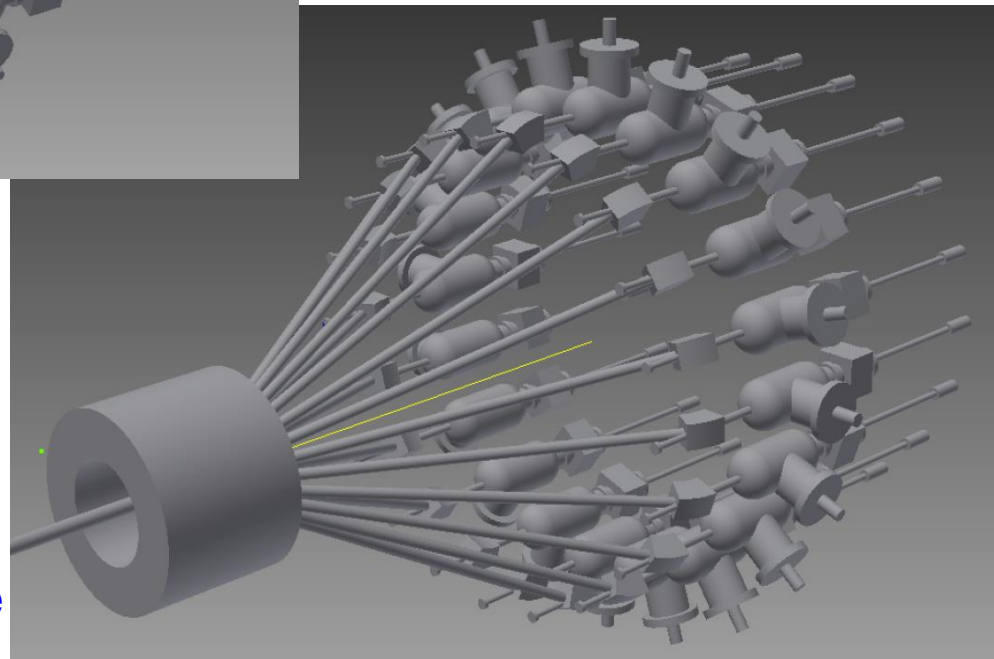
- Current polarized gun technology will still require multiple guns to meet e-RHIC requirement. A variety of concepts shall be considered to combine multiple e-guns.
- Collaboration to determine feasibility of combining Jlab type polarized e-guns and detailed studies will be performed:
- Identical energy beams and the use of RF to kick beam pairs onto a common axis.
- . Magnetic steering of different energy beams onto a common axis and then use RF to compensate individual bunch energy.
- Apply the Gatling gun principles to multi-single cathode gun configuration.

# Gatling Concept and the Multiple-Gun Approach



Two polarized e-beams from JLAB type guns may be combined using the funneling principle in collaboration with JLab

- In principle the e-beam funneling approach may be extended to multiple individual electron guns building upon the work being developed for the multi-cathode Gatling gun program.
- As part of the R&D program we will study all viable options and demonstrate the most feasible approach





# Summary

- Presented is an introduction of the Gatling Gun Development Program.
- The R&D goals and performance parameters have been presented.
- Schedule milestones and a summary of deliverables defining the program was presented.
- Adequate resources will be essential to demonstrate and characterize the R&D Gatling gun and combined gun systems.
- The results of this R&D shall be used in the detailed design and construction of a low risk high intensity polarized electron source for e-RHIC.

# Acknowledgments

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